RESEARCH

Combining Ability of Binary Mixtures of Introduced, Cool- and Warm-Season Grasses and Legumes

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ABSTRACT

When two forage species are grown together they can be compatible, compete, or allelopathic with each other. We estimated the combining ability effects for introduced, cool- (CS) and warm-season (WS) grasses and legumes grown in binary mixtures. Six pure stands and 15 mixtures were transplanted into field plots in a replicated randomized block design at Woodward, OK. Plots were harvested three times a year over a 2 yr period. Each harvest was analyzed as a mixed model combining ability analysis. The dependent variables were forage dry matter (DM) and crude protein (CP) yield. Specific combining ability (SCA) effects for DM yield were either zero or negative for mixtures of CS grasses or mixtures of WS grasses. For DM yield the SCA effects were either zero or positive for CS grass-legume mixtures or zero or negative for WS grass-legume mixtures. A few grass–grass and grass–legume mixtures produced positive SCA effects; but, their species compositions were highly skewed toward one species. When SCA effects are zero, species compete with each other. This was the case for yellow bluestem [*Bothriochloa ischaemum* (L.) Keng. var. *ischaemum* (Hack.) Celarier and Harlan]–legume mixtures. Yellow bluestem-legume mixtures averaged 59% yellow bluestem: 41% legume DM forage across harvests. Yellow bluestem-legume mixtures may be a suitable forage production system for the Southern Plains. Long-term grazing studies are needed to determine the sustainability of these mixtures.

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Abbreviations: CP, crude protein; CS, cool season; DM, dry matter; GCA, general combining ability; LTA, long-term average; SCA, specific combining ability; WS, warm season.

Agricultural producers need information concerning combining abilities for cool (CS)- and warm-season (WS) species presently grown or having the potential of being grown for forage. Grazing systems using forage legumes increase animal production (Fribourg et al., 1979; Jung et al., 1985; Rayburn et al., 1980; Stricker et al., 1979). Pastures with legumes have greater crude protein (CP) content, higher digestibility, and increased mineral composition for livestock diets, resulting in greater forage intake and animal performance (Marten, 1985). Kroth et al. (1982) reported the N inputs from birdsfoot trefoil (*Lotus corniculatus* L.) and alfalfa (*Medicago sativa* L.) were 115 and 200 kg N ha^{-1}, respectively, annually. Residual N fixed by legumes increased subsequent forage growth of ryegrass (*Lolium multiflorum* Lam.) and was equivalent to fertilization with 111 kg N ha^{-1} for arrowleaf clover (*Trifolium vesiculosum* Savi) and 121 kg N ha^{-1} for a mixture

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of arrowleaf and crimson clovers (*Trifolium incarnatum* L.; Lynd et al., 1984).

Species grown in mixtures can be compatible by avoiding competition with each other; be competitive by using the same resources; or be allelopathic with each other (Harper, 1977). These relationships are difficult to measure in traditional plot and grazing experiments because dominant species in mixtures have a competitive advantage at the onset of measuring their compatibility and interactions. Combining abilities for species and for mixtures of species can be estimated using a combining ability analysis of variance. This type of analysis has typically been used by plant and animal breeders to estimate combining abilities of breeding lines (Griffing, 1956). Springer et al. (2001) used this approach to estimate combining abilities of binary mixtures of native grasses and legumes and found it useful for choosing compatible grass–legume mixtures. They found that the compatibility of species could not be predicted solely on dry matter yields. Compatible mixtures, however, were identified with greater confidence when other variables, such as crude protein yield and visual observations were taken into account.

Researchers have employed a variety of laboratory, greenhouse, and field studies to show the allelopathic and competitive effects of tall fescue (*Festuca arundinacea* Schreb.) and white clover (*Trifolium repens* L.) on other plant species (McCloud and Mott, 1953; Peters, 1968; MacFarlane et al., 1982; Springer et al., 1996; Springer, 1996). Plant species compatibilities exist for mixtures of tall fescue with either birdsfoot trefoil or white clover (Pederson and Brink, 1988; Beuselinck et al., 1992; Springer et al., 1996) and for switchgrass [*Panicum virgatum* L.], indiangrass [*Sorghastrum nutans* (L.) Nash], or sideoats grama (*Bouteloua curtipendula* Michx.) mixed with either purple prairie-clover [*Petalostemon purpureum* (Vent.) Rydb.], roundhead lespedeza (*Lespedeza capitata* Michx.), leadplant (*Amorpha canescens* Pursh), Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacM.], catclaw sensitive brier [*Schrankia nuttallii* (DC. Standl.], or cicer milkvetch (*Astragalus cicer* L., Posler et al., 1993).

Much of the literature on the combining ability of grasses with legumes is from laboratory and greenhouse experiments using CS forage species and very little information is available regarding the combining ability of introduced CS and WS grasses and legumes under field conditions. Combining CS and WS species in grazing systems will extend the grazing season and improves overall forage quality. Finding species that combine well with each other will help lead to mixtures with increased forage production and quality and possibly utilization. Thus, our objective was to estimate the combining ability effects for introduced, CS and WS grasses and legumes grown in binary mixtures in the field.

MATERIALS AND METHODS

This experiment was conducted at the USDA-ARS, Southern Plains Range Research Station, Woodward, OK (36° 25′ N, 99° 24′ W, elevation 600 m) on an Eda loamy fine sand (mixed, thermic Lamellic Ustipsamments). Six species were used for study: 'Cimarron' alfalfa, ARS-2620 rhizomatous birdsfoot trefoil, 'Luna' intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey], 'Max-Q' novel endophyte–'Jesup' tall fescue, 'Morpa' weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees], and 'WW-Spar' yellow bluestem [*Bothriochloa ischaemum* (L.) Keng. var. *ischaemum* (Hack.) Celarier and Harlan]. Alfalfa and the WS grasses, yellow bluestem and weeping lovegrass, are adapted to the subhumid Southern Plains and are used for forage in the region. The adaptability of birdsfoot trefoil, and the CS grasses, intermediate wheatgrass and 'Max-Q' novel endophyte–'Jesup' tall fescue, is not known for the subhumid Southern Plains and these species were selected to study their forage potential in the region.

In February 2001, seed of each species was planted into 64-cell cavity trays and maintained in the greenhouse until field transplanting. Species were transplanted by hand into field plots in May 2001. Fifteen species mixtures were planted at a 1:1 ratio alternating species within and between rows. Plants were spaced 15 cm apart. Pure stands of each of the six species were also included. The field plot design was a randomized complete block replicated four times. Individual plots were 1.2 by 1.2 m. Before initiation of new spring growth, residual forage was removed from plots by burning. In mid-March each year, all plots received 67 kg ha^{-1} of P as triple superphosphate (0–46–0, N–P–K). At the same time, grass-only plots received 67 kg ha^{-1} of N as urea (46–0–0, N–P–K). In 2002 to 2003, plots were harvested three times each year when grasses were in the boot stage of growth. The average dates of harvest were 15 May, 5 July, and 1 September.

The forage dry matter yield of each plot was determined by harvesting the entire plot to a stubble height of 5 cm. The forage was weighed fresh and a 250 to 300 g representative subsample was collected. The plot subsample was separated by hand into its respective species components. Each component was weighed fresh and oven-dried at 60°C. The dry matter yield of each plot was calculated by multiplying the percentage dry matter of the oven-dried subsamples by the harvested green weight of the plot and converted to Mg ha^{-1}. The percentage of each species in mixture was calculated by dividing its dry matter weight by the total dry matter weight of the plot. Crude protein was determined using an Elementar vario MAX CN analyzer (Elementar Americas, Inc., Mt. Laurel, NJ).

The combining ability of species and species mixtures was determined using a combining ability analysis of variance (Griffing, 1956). By definition, the general combining ability (GCA) is the mean performance of a species when expressed as a deviation from the overall mean of all species combinations. The specific combining ability (SCA) is the deviation of the 'expected' value (the overall mean plus the sum of the GCAs of the two species in mixture) from the mean value of the two species in mixture. Thus, the true mean X of a forage mixture of species A and B can be expressed as

$$X = \bar{X} + GCA_{A} + GCA_{B} + SCA_{AB}$$

where $\bar{X}$ is the mean of all mixtures, and the GCA and SCA are the general and specific combining abilities of species A and B

Table 1. Precipitation and temperatures at Woodward, OK in 2002 and 2003.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Precipitation (mm)												
Long-term average	13	25	46	53	102	81	66	74	58	48	36	20
2002	2	0	2	86	45	82	75	57	48	234	5	24
2003	2	10	47	35	37	111	1	93	75	10	16	17
Monthly average high temperature (°C)												
Long-term average	9	12	17	23	27	32	35	34	29	24	16	10
2002	11	12	16	23	26	32	33	34	30	21	16	9
2003	10	8	17	23	26	28	36	35	26	23	14	12
Monthly average low temperature-low (°C)												
Long-term average	–6	–3	2	7	13	18	21	19	15	8	1	–4
2002	–3	–3	–2	9	12	19	21	20	16	8	2	–2
2003	–4	–4	2	8	12	17	22	21	13	9	3	–2

(Falconer, 1981). Similar to the concept of "Relative Yield Total" as summarized by Harper (1977). Springer et al. (2001) defined an SCA effect equal to 0 to indicate competition between species, for example, the species make similar demands on resources. When SCA equals 0, each species' contribution to the mixture is equal to its expected share. An SCA effect greater than 0 to denote compatibility between species, for example, the species avoided competition by making different demands on resources. When SCA is >0, each species' contribution to the mixture is greater than its expected share. An SCA <0 suggest an incompatibility between species, for example, the species have a negative interaction with each other. If SCA is <0, each species contribution to the mixture is less than its expected share.

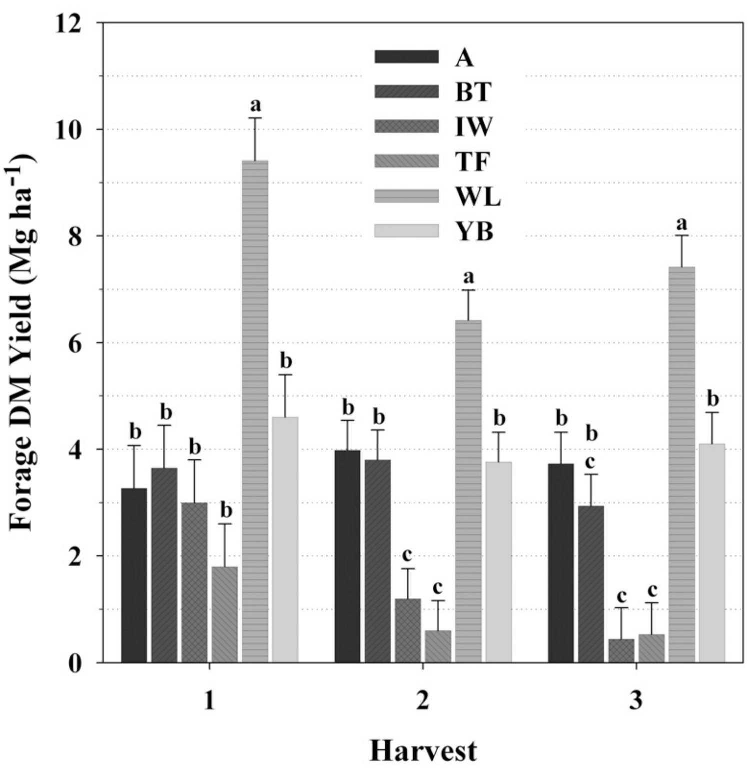

Figure 1. Forage dry matter (DM) yield for pure stands of 'Cimarron' alfalfa (A), rhizomatous birdsfoot trefoil (BT), 'Luna' intermediate wheatgrass (IW), 'Max-Q' novel endophyte–'Jesup' tall fescue (TF), 'Morpa' weeping lovegrass (WL), and 'Spar' yellow bluestem (YB) at three harvests (1, 15 May; 2, 5 July; and 3, 1 September) averaged across years (2002–2003). Within harvest, bars with the same letter are not significantly different at $P \leq 0.05$ (adjusted Tukey test).

Each harvest was analyzed separately as a mixed model analysis of variance with blocks within year as random effects and year as a repeated measure (Littell et al., 1996; SAS Institute, 1999). Fixed effects were the GCA and SCA (Griffing, 1956) of species and species mixtures. The dependent variables were forage dry matter yield and CP yield.

Pure stands were analyzed separately by harvest as a mixed model analysis of variance with blocks within year as random effects and year as a repeated measure (Littell et al., 1996; SAS Institute, 1999). Fixed effects were species pure stands. The dependent variables were forage dry matter yield and CP yield.

RESULTS

The April through September rainfall was 41 mm below the long-term average (LTA) in 2002 and 82 mm below the LTA in 2003 (Table 1). Averaged across years 2001–2002, the cumulative rainfall for April through September was 62 mm below the LTA. The average high and low temperatures were near the LTA during April through September 2002 to 2003 (Table 1).

Pure Stands

Weeping lovegrass in pure stands had greater ($P \leq 0.05$) forage DM yield than any other species for harvest 1, and there were no differences ($P \geq 0.05$) among forage DM yields of yellow bluestem, alfalfa, birdsfoot trefoil, intermediate wheatgrass, and tall fescue. The general trends for harvests 2 and 3 were similar. Weeping lovegrass had greater ($P \leq 0.05$) forage DM yield than other species, and during the CS, tall fescue, and intermediate wheatgrass had less ($P \leq 0.05$) DM yield than did yellow bluestem, alfalfa, or birdsfoot trefoil (Fig. 1).

Yellow bluestem, weeping lovegrass, alfalfa, and birdsfoot trefoil had greater ($P \leq 0.05$) CP yield than either intermediate wheatgrass or tall fescue for harvest

1 (Fig. 2). At harvest 2, weeping lovegrass, alfalfa, and birdsfoot trefoil were not different ($P \geq 0.05$) for CP yield. Likewise, yellow bluestem and weeping lovegrass were not different ($P \geq 0.05$), and tall fescue, intermediate wheatgrass and yellow bluestem were not different ($P \geq 0.05$) for CP yield (Fig. 2).

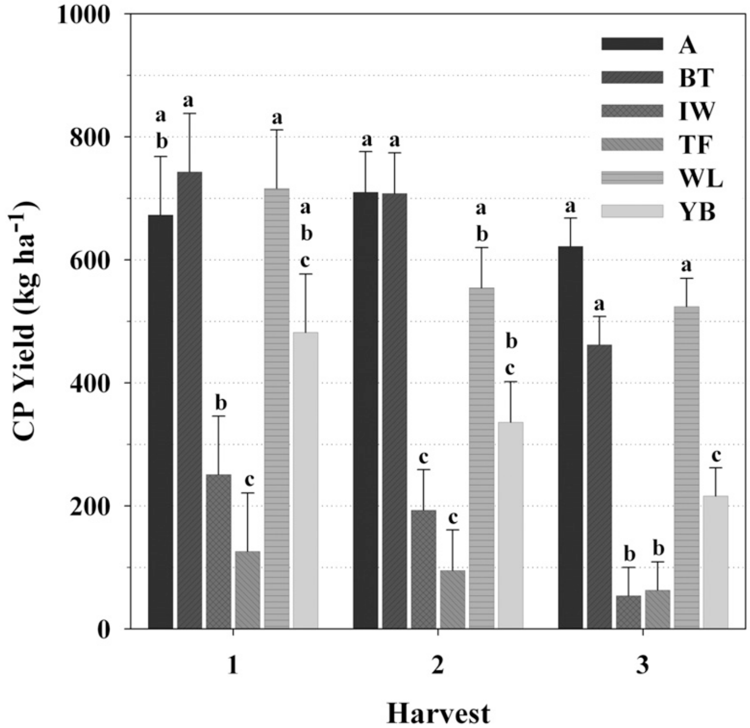

Figure 2. Crude protein (CP) yield for pure stands of 'Cimarron' alfalfa (A), rhizomatous birdsfoot trefoil (BT), 'Luna' intermediate wheatgrass (IW), 'Max-Q' novel endophyte–'Jesup' tall fescue (TF), 'Morpa' weeping lovegrass (WL), and 'Spar' yellow bluestem (YB) at three harvests (1, 15 May; 2, 5 July; and 3, 1 September) averaged across years (2002–2003). Within harvest, bars with the same letter are not significantly different at $P \leq 0.05$ (adjusted Tukey test).

Combining Ability Effects of Mixed Stands

The GCA effect for weeping lovegrass forage DM yield was positive for all harvests, and all other species GCA effects were either zero or negative (Table 2). The SCA effects for forage DM yield at harvest 1 were not different ($P \geq 0.05$) from zero (Table 2). For harvests 2 and 3 the general trend for forage DM yield of grass-grass mixtures was for mixtures of CS and WS grasses to have zero to positive SCA effects. The SCA effects were either zero or negative for mixtures of either CS or WS grasses (Table 2). For forage DM yield for harvests 2 and 3, CS grass–legume mixtures had either zero or positive SCA effects, whereas, WS grass–legume mixtures had either zero or negative SCA effects (Table 2). The SCA effects for forage DM yield of alfalfa combined with birdsfoot trefoil were zero. Forage DM yield averaged 4.74, 4.21, and 4.96 Mg ha^{-1} for harvests 1, 2, and 3, respectively.

The GCA effects for alfalfa, birdsfoot trefoil, and weeping lovegrass CP yield were either zero or positive for all harvests (Table 3). The GCA effects for intermediate wheatgrass, tall fescue, and yellow bluestem CP yield were negative for all harvests (Table 3). The SCA effects for CP yield were negative for all harvests for a mixture of intermediate wheatgrass and tall fescue (Table 3). For mixtures of CS and WS grasses the CP yield for all harvests were either zero or positive. The SCA effects for CP yield were positive or zero for all harvests for a mixture of weeping lovegrass and yellow bluestem (Table 3). The SCA effects of CS grass–legume mixtures were either zero or positive for CP yield for all harvests. The SCA effects of WS grass–legume mixtures were either zero or negative for CP yield for all harvests. The SCA effects for CP yield of alfalfa combined with birdsfoot trefoil were zero for harvests 1 and 2 and negative for harvest 3 (Table 3). Yield of CP averaged 510, 525, and 450 kg ha^{-1} for harvests 1, 2, and 3, respectively.

Species Composition of Mixtures

Although the plant population ratio was initially 1:1 for mixtures, the species composition of forage DM yield of mixtures that included weeping lovegrass all favored weeping lovegrass (Table 4). In mixtures with the legumes, the percentage of intermediate wheatgrass and tall fescue decreased from harvest 1 to harvest 2, but increased from harvest 2 to harvest 3. Yellow bluestem-legume mixtures averaged 59% yellow bluestem: 41% legume across harvests and alfalfa accounted for 43 to 61% of the forage DM yield for the alfalfa-birdsfoot trefoil mixture.

DISCUSSION

Springer et al. (1996, 2001) found that compatible mixtures were identified with greater confidence when all variables, such as forage yield, forage quality, species composition, and visual observations, were taken into account. With this in mind, our objective was to estimate the combining abilities for introduced CS and WS grasses and legumes grown in binary mixtures in the field with the goal of finding species that would complement each other by either extending the grazing season and/or boosting the quality of the forage that livestock consume. Ideally, species that produced an over-yield when in mixture, a positive SCA effect, would be suitable candidates. Among grass–grass mixtures and with only one exception, weeping lovegrass consistently had either zero or positive SCA effects for both forage DM yield and CP yield. Although the plant population ratio was 1:1 for mixtures, weeping lovegrass accounted for ≥ 95% of the forage DM yield of grass–grass mixtures.

Among grass–legume mixtures, intermediate wheatgrass and tall fescue with either alfalfa or birdsfoot trefoil had either zero or positive SCA effects for both forage DM yield and CP yield. For intermediate wheatgrass–legume mixtures, legumes accounted for

Table 2. General combining ability (GCA) and specific combining ability (SCA) for species and species mixtures for forage DM yield (Mg ha⁻¹) for harvests 1 to 3.†

Species A of mixture	Species B of mixture	Harvest 1‡	Harvest 2	Harvest 3
		Mg ha⁻¹		
GCA				
Pure stands				
A§	–	–1.10***	–0.04NS¶	–0.10NS
BT	–	–0.71**	–0.29*	–1.09***
IW	–	–1.19***	–0.95***	–1.30***
TF	–	–0.84***	–0.82***	–1.17***
WL	–	5.60***	2.38***	3.59***
YB	–	–1.87***	–0.28*	0.07NS
SCA				
Grass–grass mixtures				
IW	TF	–0.32NS	–1.86***	–2.12***
IW	WL	0.30NS	0.86***	1.00*
IW	YB	–0.38NS	0.02NS	0.30NS
TF	WL	0.16NS	0.58*	1.19**
TF	YB	–0.27NS	0.70**	0.51NS
WL	YB	0.34NS	–0.25NS	–1.25**
Grass–legume mixtures				
IW	A	0.22NS	0.26NS	0.79*
IW	BT	0.18NS	0.72*	0.02NS
TF	A	0.05NS	0.35NS	0.52NS
TF	BT	0.38NS	0.24NS	–0.11NS
WL	A	–0.65NS	–0.47*	–1.33***
WL	BT	–0.15NS	–0.73**	0.39NS
YB	A	0.55NS	–0.19NS	0.39NS
YB	BT	–0.24NS	–0.27NS	0.06NS
Legume–legume mixture				
A	BT	–0.17NS	0.05NS	–0.37NS
$\bar{X}$		4.74	4.21	4.96
Pooled GCA effects		***	***	***
Pooled SCA effects		NS	***	***

*Combining ability effects are significantly different from zero at $P \le 0.1$ (*t* test).

**Combining ability effects are significantly different from zero at $P \le 0.05$ (*t* test).

***Combining ability effects are significantly different from zero at $P \le 0.01$(*t* test).

†The true mean X of a forage mixture containing species A and B can be expressed as $X = \bar{X} + GCA_A + GCA_B + SCA_{AB}$ where $\bar{X}$ is the mean of all mixtures, and the GCA and SCA are the general and specific combining abilities of species A and B.

‡Harvest 1, 15 May; Harvest 2, 5 July; Harvest 3, 1 September.

§A, alfalfa; BT, birdsfoot trefoil; IW, intermediate wheatgrass; TF, tall fescue; WL, weeping lovegrass; and YB, yellow bluestem.

¶NS, not significantly different from zero.

Table 3. General combining ability (GCA) and specific combining ability (SCA) for species and species mixtures for forage crude protein (CP) yield (kg ha⁻¹) for harvests 1 to 3.†

Species A of mixture	Species B of mixture	Harvest 1	Harvest 2	Harvest 3
		kg ha⁻¹		
GCA				
Pure stands				
A§	–	60.*	165***	200***
BT	–	75*	70***	–35NS
IW	–	–95***	–85***	–90***
TF	–	–85***	–75***	–75***
WL	–	260***	65***	100***
YB	–	–220***	–140***	–100***
SCA				
Grass–grass mixtures				
IW	TF	–140**	–270***	–235***
IW	WL	30NS¶	70**	70*
IW	YB	–75NS	–35NS	–55NS
TF	WL	90*	95***	115***
TF	YB	–45NS	15NS	–30NS
WL	YB	120**	125***	40NS
Grass–legume mixtures				
IW	A	75NS	75**	180***
IW	BT	110**	160***	45NS
TF	A	20NS	105***	95**
TF	BT	75NS	55NS	55NS
WL	A	–125**	–160***	–235***
WL	BT	–115**	–130***	10NS
YB	A	50NS	–25NS	55NS
YB	BT	–50NS	–90**	–10NS
Legume–legume mixture				
A	BT	–20NS	5NS	–95**
$\bar{X}$		510	525	450
Pooled GCA effects		***	***	***
Pooled SCA effects		**	***	***

*Combining ability effects are significantly different from zero at $P \le 0.1$(*t* test).

**Combining ability effects are significantly different from zero at $P \le 0.05$ (*t* test).

***Combining ability effects are significantly different from zero at $P \le 0.01$ (*t* test).

†The true mean X of a forage mixture containing species A and B can be expressed as $X = \bar{X} + GCA_A + GCA_B + SCA_{AB}$ where $\bar{X}$ is the mean of all mixtures, and the GCA and SCA are the general and specific combining abilities of species A and B.

‡Harvest 1, 15 May; Harvest 2, 5 July; Harvest 3, 1 September.

§A, alfalfa; BT, birdsfoot trefoil; IW, intermediate wheatgrass; TF, tall fescue; WL, weeping lovegrass; and YB, yellow bluestem.

¶NS, not significantly different from zero.

87 to 98% of the forage DM yield and for tall fescue–legume mixtures, legumes accounted for 64 to 95% of the forage DM yield. Weeping lovegrass–legume mixtures had either zero or negative SCA effects for both forage DM yield and CP yield. Similar to weeping lovegrass-grass mixtures, weeping lovegrass accounted for 85 to 98% of the forage DM yield when in combination with legumes. With only one exception, the SCA effects were zero for yellow bluestem–legume mixtures for forage DM yield and CP yield. Yellow bluestem accounted for 43 to 85% of the forage DM yield for yellow bluestem–legume mixtures.

The only legume–legume mixture was alfalfa and birdsfoot trefoil. With only one exception, the SCA effects were zero for alfalfa–birdsfoot trefoil mixtures for forage DM yield and CP yield. Alfalfa accounted for 43 to 61% of the forage DM yield for the alfalfa–birdsfoot trefoil mixture.

Table 4. Average species composition of each mixture for harvests 1 to 3; (based on aboveground dry matter). The plant population was a 1:1 ratio for each mixture.

Species A of mixture	Species B of mixture	Harvest 1†		Harvest 2		Harvest 3	
		Species A	Species B	Species A	Species B	Species A	Species B
		%					
Grass–grass mixtures							
IW‡	TF	47	53	17	83	1	99
IW	WL	1	99	1	99	1	99
IW	YB	1	99	1	99	1	99
TF	WL	1	99	1	99	1	99
TF	YB	10	90	1	99	1	99
WL	YB	99	1	97	3	95	5
Grass–legume mixtures							
IW	A	13	87	2	98	9	91
IW	BT	13	87	2	98	6	94
TF	A	35	65	5	95	30	70
TF	BT	36	64	11	89	33	67
WL	A	92	8	85	15	89	11
WL	BT	98	2	93	7	98	2
YB	A	43	57	47	53	61	39
YB	BT	54	46	61	39	85	15
Legume–legume mixture							
A	BT	43	56	61	39	44	56

†Harvest 1, 15 May; harvest 2, 5 July; harvest 3, 1 September.

‡A, alfalfa; BT, birdsfoot trefoil; IW, intermediate wheatgrass; TF, tall fescue; WL, weeping lovegrass; and YB, yellow bluestem.

Within the parameters of this experiment, although a few grass–grass and grass–legume mixtures produced greater yields than their expected yields (positive SCA effects), their species compositions were highly skewed toward one species. Over time the primary species would likely replace the secondary species altogether. When SCA effects are zero, a competition between species exists, for example, the species make similar demands on resources and each species' contribution to the mixture is equal to its expected share. This was the case for DM yield and CP yield for yellow bluestem–legume mixtures. Yellow bluestem–legume mixtures averaged 59% yellow bluestem: 41% legume DM forage across harvest. In general, as the growing season progressed, the percentage of yellow bluestem forage increased in the mixture. Masters and Britton (1988) documented an increase in the aboveground DM yield of fertilized yellow bluestem in response to clipping regardless of the moisture regime and showed that clipping had no effect on DM yield of unfertilized yellow bluestem regardless of the moisture regime. Since grass–legume mixtures were not fertilized with N in this experiment, yellow bluestem undoubtedly benefited from the release of N from decaying roots and nodules after forage harvests (Heichel, 1987).

Several items were not addressed by this research. First cultivar differences were not addressed. In a similar experiment, Springer et al. (1996) found differences in combining ability between tall fescue cultivars and legume species. Second, selective grazing by livestock was not addressed. Differential palatability would be a major factor but grazing management could mitigate that. Third, growing season precipitation was generally below average during the experiment. Additional moisture may have increased the yields of CS grasses allowing them to compete better early in the growing season.

CONCLUSIONS

Given the conditions of this experiment, weeping lovegrass was adapted to the subhumid environment of northwest Oklahoma and should probably be grown in a monoculture. It grows well on coarse textured soils with limited moisture giving it a competitive advantage. In contrast, 'Luna' intermediate wheatgrass and 'Max Q' novel endophyte–'Jesup' tall fescue are not adapted to the subhumid environment of northwest Oklahoma. Prolonged drought often reduces the stands of perennial CS grasses to a point that they have to be reseeded (Gillen and Berg, 2005). Alfalfa, rhizomatous birdsfoot trefoil, and yellow bluestem also are adapted well to this environment. This experiment suggests that alfalfa and rhizomatous birdsfoot trefoil are direct competitors with yellow bluestem and that yellow bluestem–legume mixtures may be a suitable forage production system for the Southern Plains. However, long-term grazing studies are needed to determine the sustainability of these grass–legume mixtures.

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